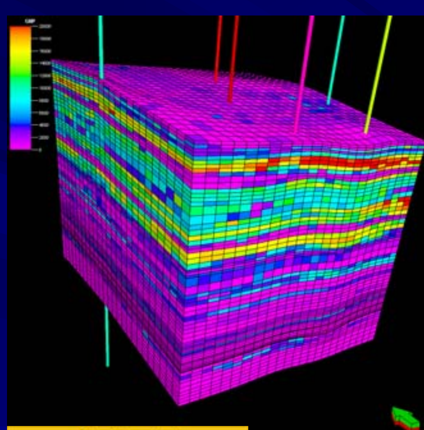
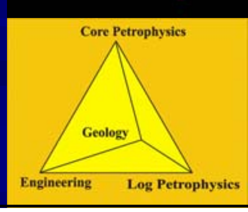
Summary

Fundamental Model Properties





- **Basic Architecture**
  - Structural Top
  - Thickness
  - Facies Architecture
  - Connectivity (transmissibility)
  - # Layers – Gridcell dimensions
- **Reservoir Rock Properties**
  - Porosity
    - Compressibility
  - Permeability
    - Absolute
    - Relative Permeabilities (krw,krg)
  - Saturations
    - Wireline log parameters
    - Capillary Pressure
    - Free Water Level
    - History
- Fluid Properties
  - Density (=f(P,T))
  - Viscosity (=f(T))
  - Expansion Factor (Eg=f(P,T))

Integrated Approaches to Modeling Late Paleozoic Petroleum Reservoirs in the Greater Midcontinent

Who Should Attend:

- Geologists and engineers who are characterizing late Paleozoic reservoirs to optimize oil and gas recovery.
- Geoscientists exploring for new fields and extensions in the greater Midcontinent.

Objectives:

- Describe oil and gas plays and reservoir characterization in the context of tectonic/structural framework, sequence stratigraphy, and lithofacies distribution.
- Illustrate integrated geomodel development using core descriptions and analyses, wireline log analysis techniques, well tests, 3D seismic, and production histories.
- Effectively integrate recent analogs and surface exposures to define and model reservoir heterogeneity and design appropriate recovery technologies.
- Highlight case studies of carbonate, sandstone, and chert reservoirs ranging from Mississippian (Lower Carboniferous) through Lower Permian age.
- Integrate reservoir characterization in the context of reservoir systems and hydrocarbon accumulation – *re-exploration and exploitation*.
- Provide tools and insights for efficient prospecting and development for remaining oil and gas resources.

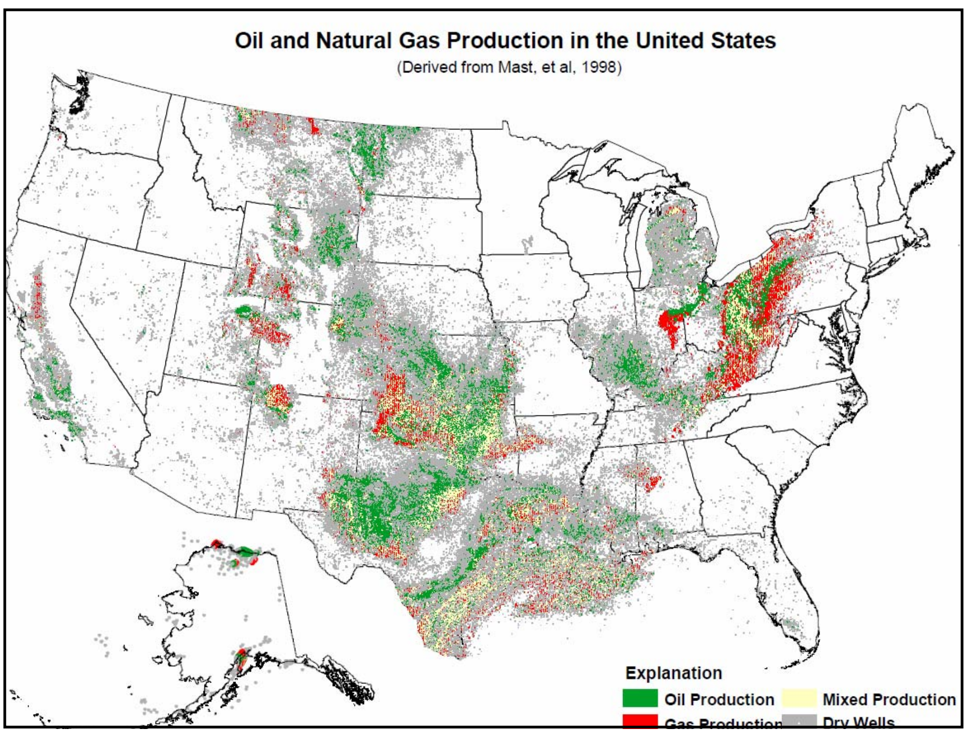
Integrated Approaches to Modeling Late Paleozoic Petroleum Reservoirs in the Greater Midcontinent

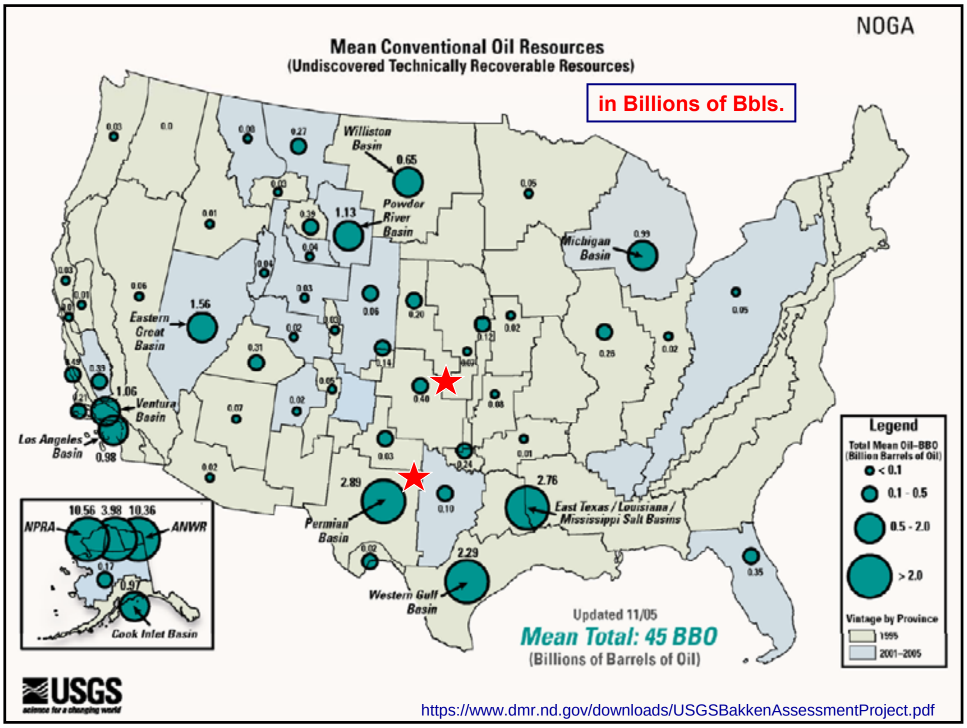
Content:

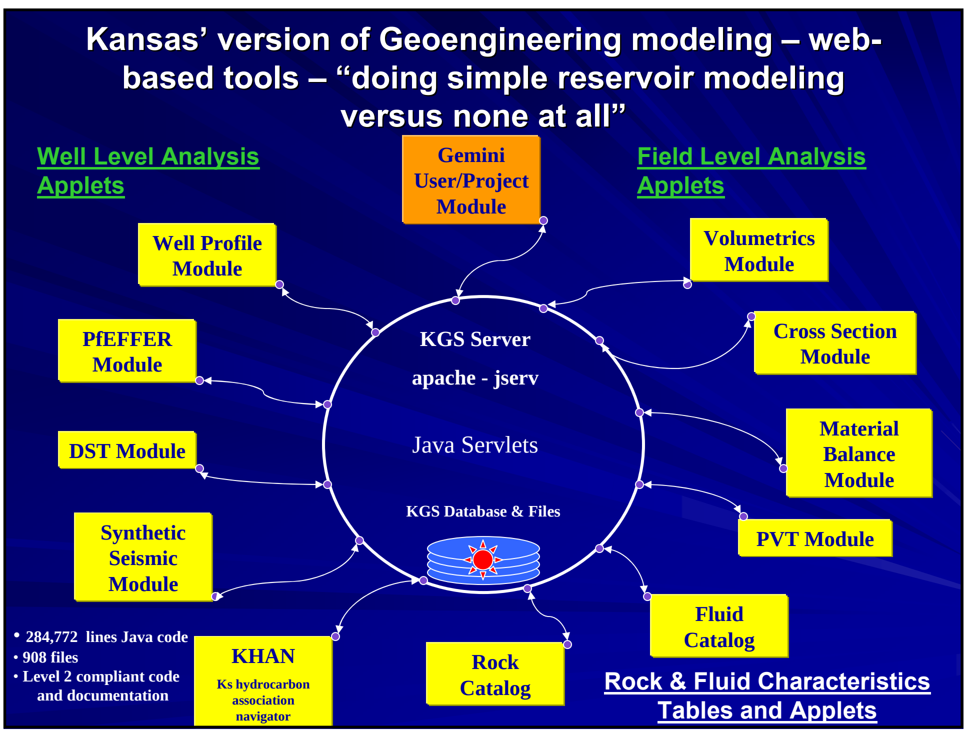
- Regional structural/tectonic framework during the late Paleozoic.
- Variations in sequence stratigraphy and reservoir architecture of late Paleozoic strata in the Midcontinent.
- Common reservoir lithofacies and their Recent analogs.
- Petrofacies and pore typing approach to quantitative reservoir analysis and modeling petroleum reservoirs, roles of diagenesis.
- Case studies based on integrated geo-engineering modeling of Mississippian, Pennsylvanian, and Permian reservoirs:
  - carbonate ooid and grainstone shoals
  - phylloid algal mounds and related lithofacies
  - incised valley and estuarine sandstones
  - Low resistivity, often low permeability spiculitic bioclastic buildups that comprise shelf and shelf margin environments.

Take Home Points of Short Course

- Basement structures and tectonic events affecting them are important in defining location and properties of reservoirs.
- Process-based field, outcrop, and Recent analogs provide more appropriate, accurate interpolation of reservoir properties.
- Late Paleozoic reservoirs are dominated by depositional fabric selective diagenesis.
- Establishing petrofacies and pore types is essential to accurate calculations of water saturations, volumetrics, ROIP, establishing permeability correlations and predicting fluid flow.
- Infill locations and new pays within oil and gas fields remain significant targets for IOR in mature regions; requires comprehensive, integrated approach.
- Re-exploration and exploitation of mature producing areas can be substantially benefited by access to and mining of large data sets – digital and electronic data – logs, production, core/samples and descriptions, *in an integrated and quantitative manner.*



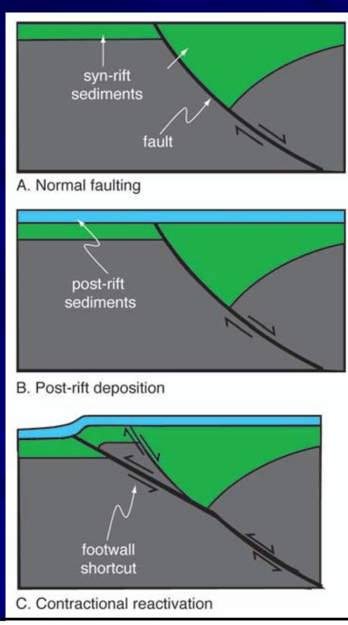

NOGA
Mean Conventional Oil Resources
(Undiscovered Technically Recoverable Resources)
in Billions of Bbls.
Williston Basin
Powder River Basin
Michigan Basin
Eastern Great Basin
Ventura Basin
Los Angeles Basin
Permian Basin
East Texas / Louisiana / Mississippi Salt Basins
Western Gulf Basin
NPRA
ANWR
Cook Inlet Basin
Legend
Total Mean Oil-BBO (Billion Barrels of Oil)
< 0.1
0.1 - 0.5
0.5 - 2.0
> 2.0
Vintage by Province
1995
2001-2005
Updated 11/05
Mean Total: 45 BBO
(Billions of Barrels of Oil)
USGS
https://www.dmr.nd.gov/downloads/USGSBakkenAssessmentProject.pdf


Kansas' version of Geoengineering modeling – web-based tools – "doing simple reservoir modeling versus none at all"
Well Level Analysis Applets
Gemini User/Project Module
Field Level Analysis Applets
Well Profile Module
Volumetrics Module
PfEFFER Module
Cross Section Module
KGS Server
apache - jserv
Java Servlets
KGS Database & Files
DST Module
Material Balance Module
Synthetic Seismic Module
PVT Module
Fluid Catalog
Rock Catalog
KHAN
Ks hydrocarbon association navigator
• 284,772 lines Java code
• 908 files
• Level 2 compliant code and documentation
Rock & Fluid Characteristics Tables and Applets

Ancestral Rocky Mountain, Ouachita-Marathon, and Laramide tectonism were far reaching and systematically deformed shelves and shelf margins of the Midcontinent U.S.

- Baars et al. (1995) recognized continental-scale orthogonal patterns and basic similarity of structures to the San Andres fault system

Contractional reactivation of basement extensional faults

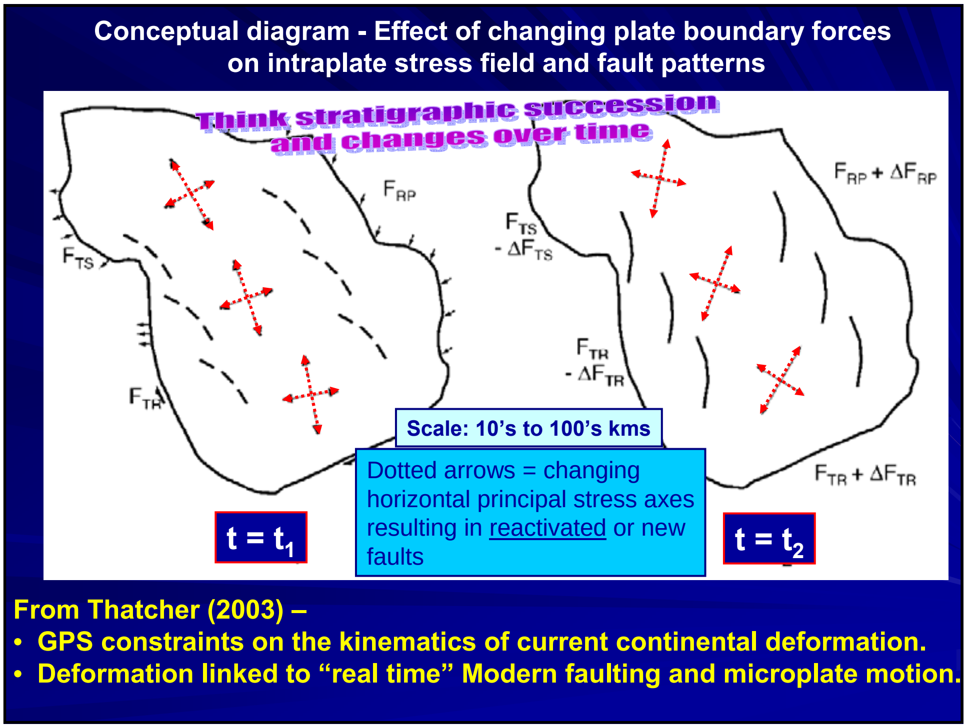


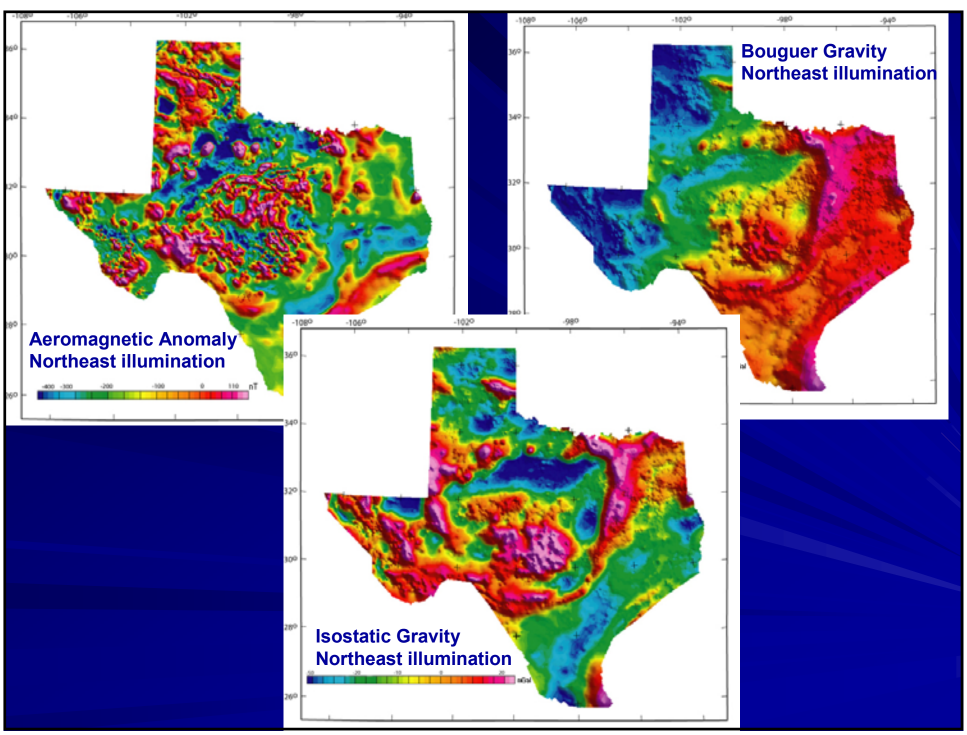
Schematic diagram of the creation of a listric normal fault (top) that is later reactivated in compression (bottom), creating a footwall shortcut. Pre-extensional rocks are shown in dark gray.

Tri-shear faults are generated during reactivation.

Upper strata may be simply draped over deeper fault.

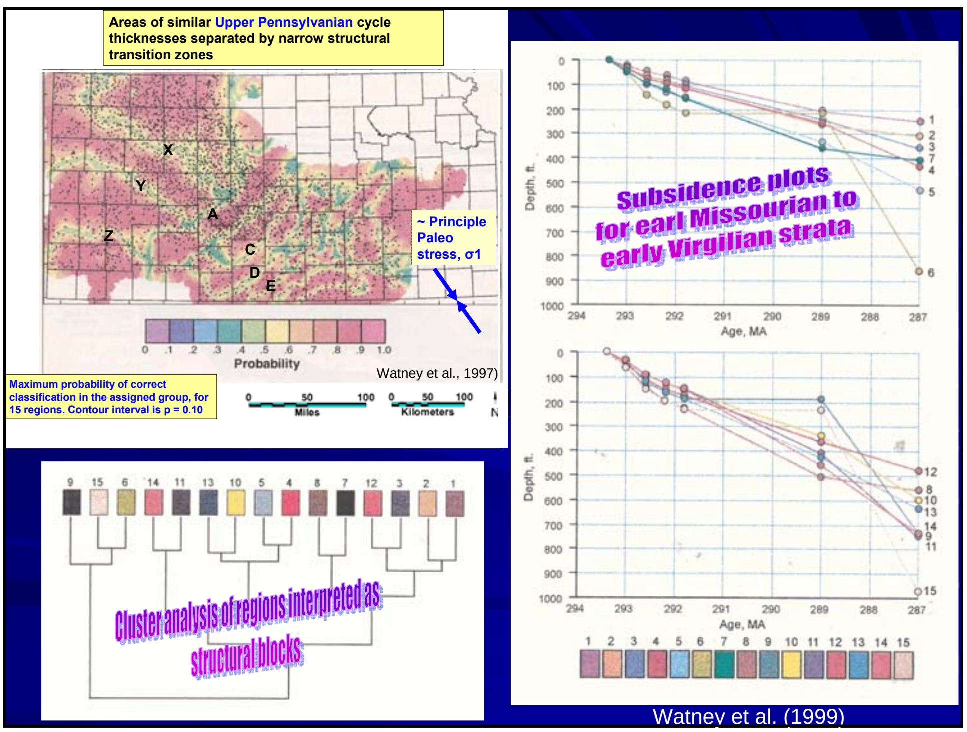
Bump (2003)

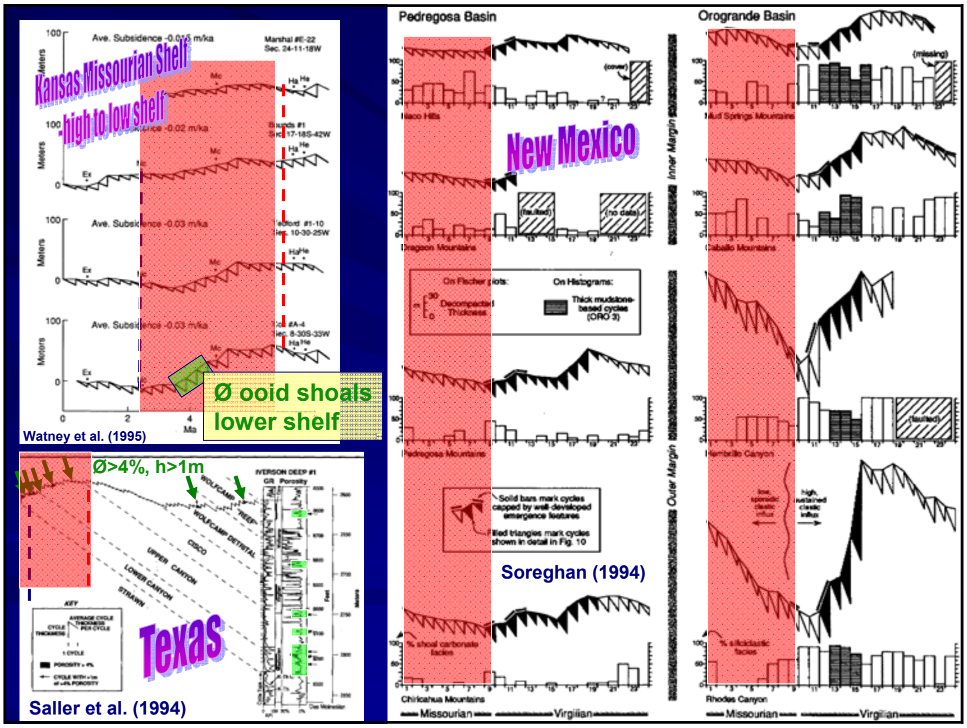

Conceptual diagram - Effect of changing plate boundary forces on intraplate stress field and fault patterns
Think stratigraphic succession and changes over time
F_{RP}
F_{TS}
F_{TR}
$F_{TS} - \Delta F_{TS}$
$F_{TR} - \Delta F_{TR}$
$F_{RP} + \Delta F_{RP}$
$F_{TR} + \Delta F_{TR}$
Scale: 10's to 100's kms
Dotted arrows = changing horizontal principal stress axes resulting in reactivated or new faults
$t = t_1$
$t = t_2$
From Thatcher (2003) –
• GPS constraints on the kinematics of current continental deformation.
• Deformation linked to "real time" Modern faulting and microplate motion.

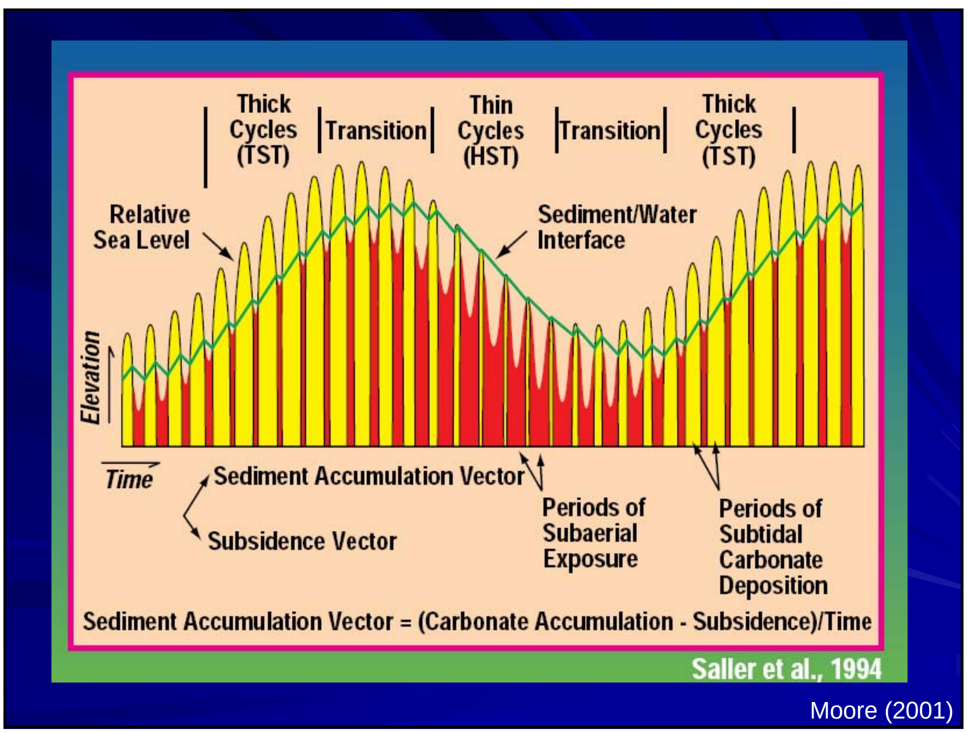

Aeromagnetic Anomaly
Northeast illumination
Bouguer Gravity
Northeast illumination
Isostatic Gravity
Northeast illumination

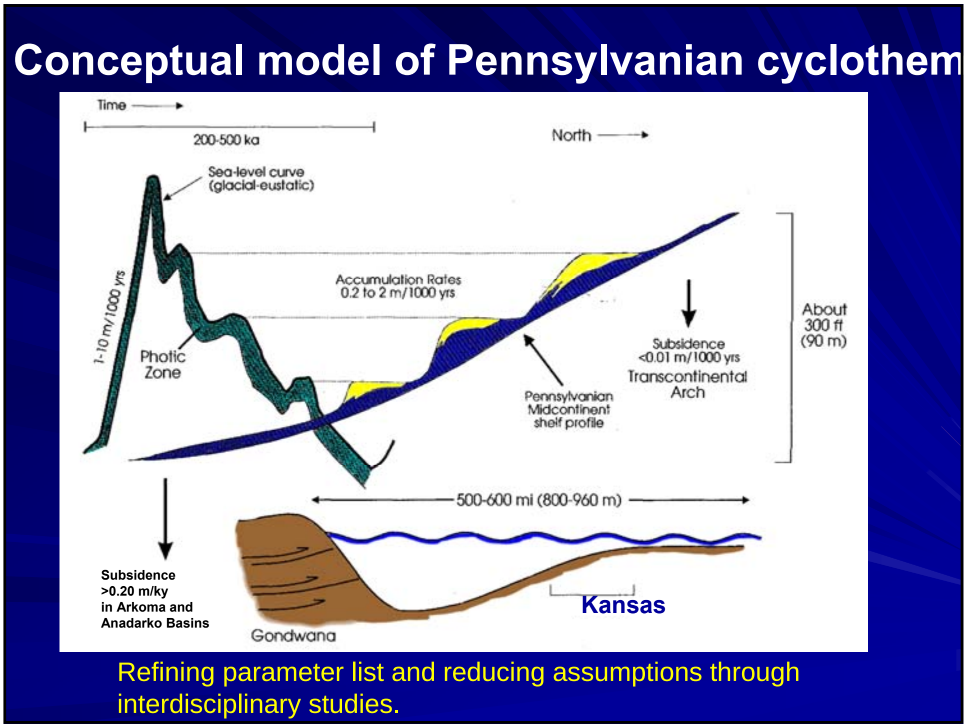
Forecasting rock properties -- Characterizing fragmentation of shelf and corresponding subsidence & tilting in context of deposition and diagenesis

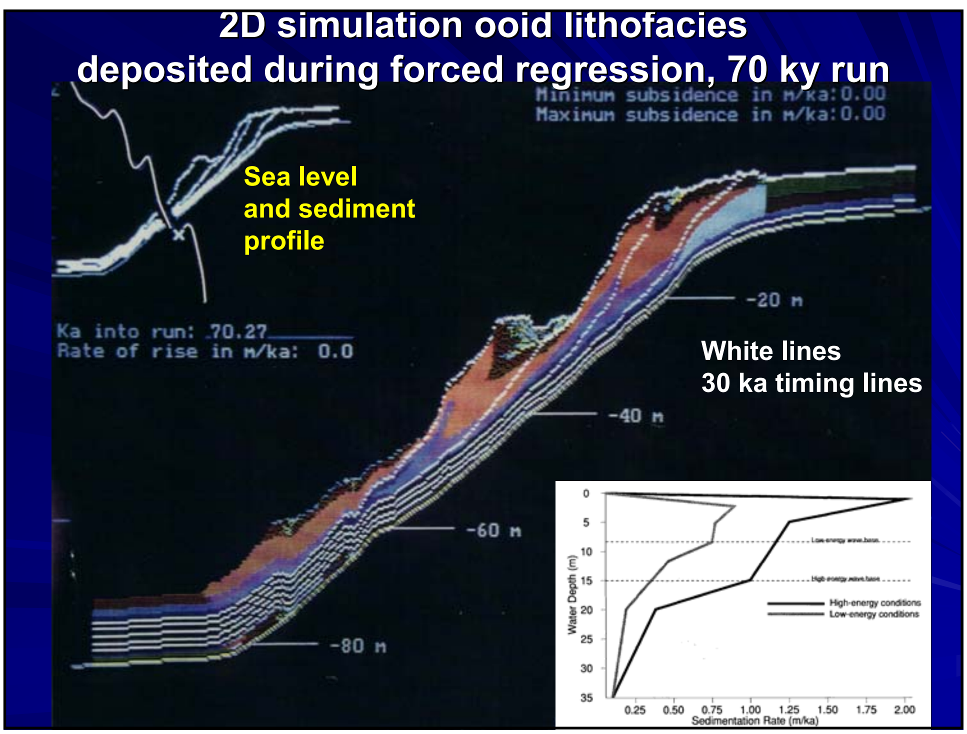
- Kinematic structural analysis – (rates, magnitude, duration of movement)
- Integrate with play and field characterization
- Spatial-temporal integration with other processes – sea level, climate, diagenetic events

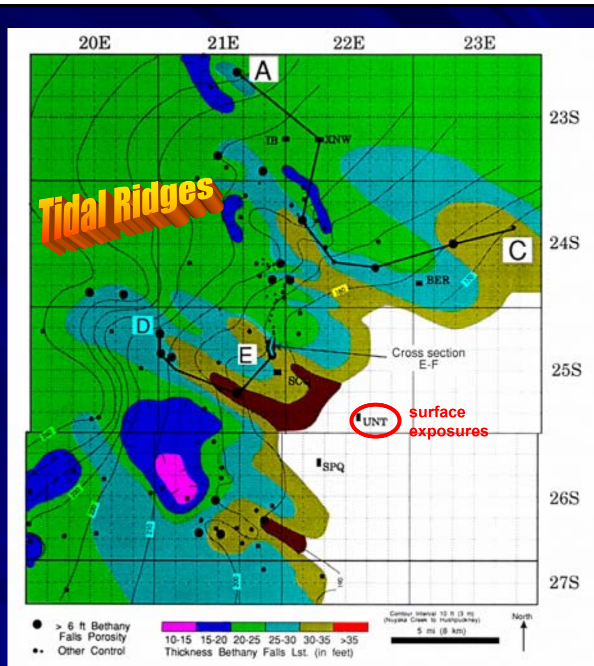



Kansas Missourian Shelf
-high to low shelf
Ø ooid shoals
lower shelf
Watney et al. (1995)
Ø>4%, h>1m
Texas
Saller et al. (1994)
Pedregosa Basin
Orogrande Basin
New Mexico
Soreghan (1994)
Missourian
Virgilian


Thick
Cycles
(TST)
Transition
Thin
Cycles
(HST)
Transition
Thick
Cycles
(TST)
Relative
Sea Level
Sediment/Water
Interface
Elevation
Time
Sediment Accumulation Vector
Subsidence Vector
Periods of
Subaerial
Exposure
Periods of
Subtidal
Carbonate
Deposition
Sediment Accumulation Vector = (Carbonate Accumulation - Subsidence)/Time
Saller et al., 1994
Moore (2001)


Conceptual model of Pennsylvanian cyclothem
Time
200-500 ka
North
Sea-level curve
(glacial-eustatic)
1-10 m/1000 yrs
Accumulation Rates
0.2 to 2 m/1000 yrs
Photic
Zone
Subsidence
<0.01 m/1000 yrs
Transcontinental
Arch
Pennsylvanian
Midcontinent
shelf profile
About
300 ft
(90 m)
500-600 mi (800-960 m)
Subsidence
>0.20 m/ky
in Arkoma and
Anadarko Basins
Gondwana
Kansas
Refining parameter list and reducing assumptions through
interdisciplinary studies.


2D simulation ooid lithofacies
deposited during forced regression, 70 ky run
Minimum subsidence in m/ka:0.00
Maximum subsidence in m/ka:0.00
Sea level
and sediment
profile
Ka into run: 70.27
Rate of rise in m/ka: 0.0
-20 m
-40 m
-60 m
-80 m
White lines
30 ka timing lines
Water Depth (m)
Sedimentation Rate (m/ka)
High-energy conditions
Low-energy conditions



Thickness of Bethany Falls Limestone (shaded) overlain on isopach of Nuyaka Creek Shale to Hushpuckney Shale

- index for A-C cross section

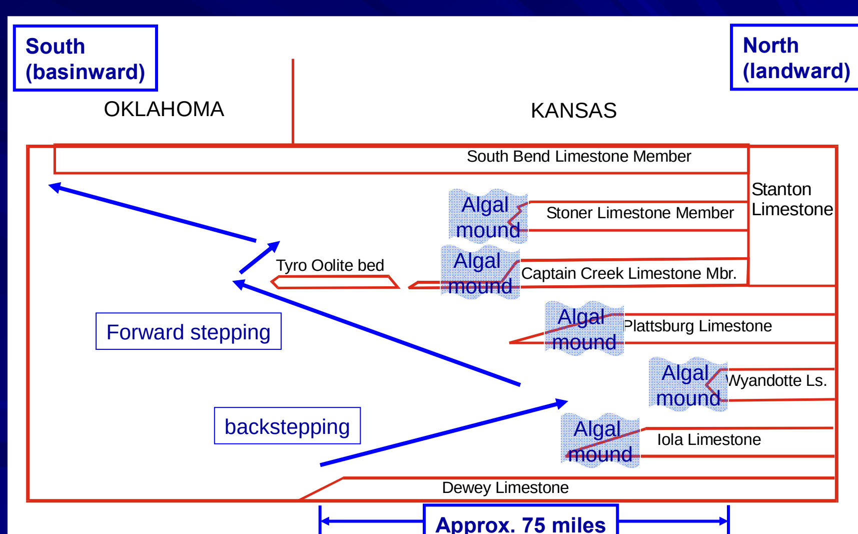
6 mi

French and Watney (1993)

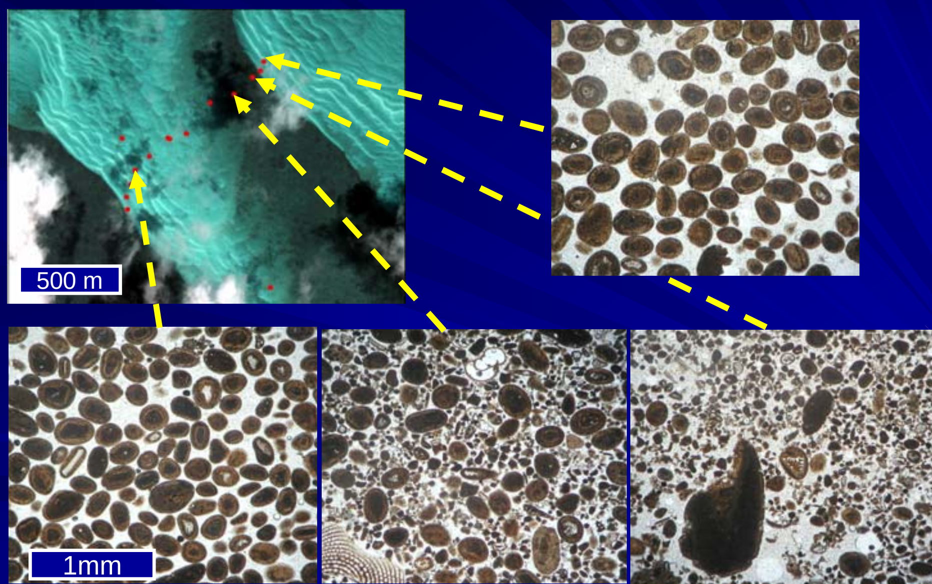
French, J.A., and Watney, W.L., 1993, Stratigraphy and depositional setting of the lower Missourian (Pennsylvanian) Bethany Falls and Mound Valley limestones, analogues for age-equivalent ooid-grainstone reservoirs, Kansas: Kansas Geological Survey Bulletin, p. 27-39.

Well control from wireline logs in oil and gas wells

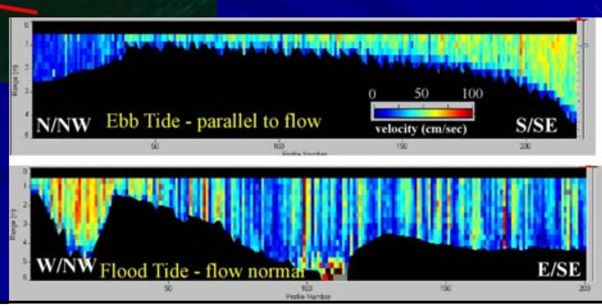
Stacking Geometry of lower Muncie Creek sequence set along the outcrop (~150 mi east)



Ramp Sediments

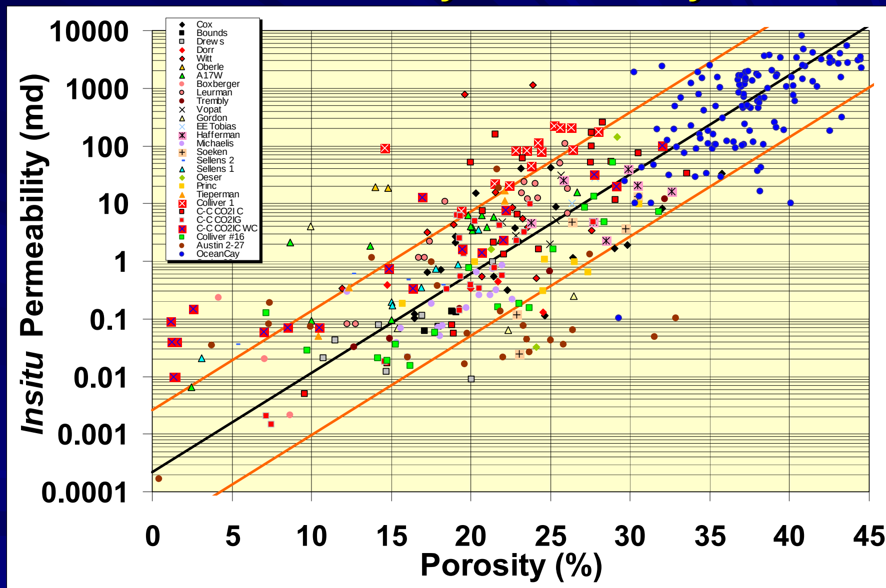


Ebb-Dominated Tidal Delta on Little Bahama Bank



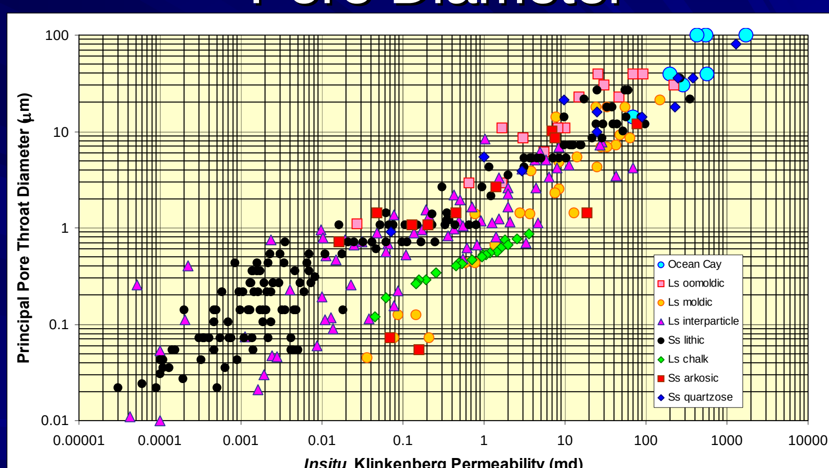
- Ebb flow over shoal
- Decreasing current velocity with distance

LKC Permeability vs Porosity



$\log_{10}k_i = 0.154\ \phi - 3.21$ (SE=6X)
$\log_{10}k_i = 0.090\ \phi + 0.47\ \mathrm{MCI} - 3.2$ (SE=5.5X)

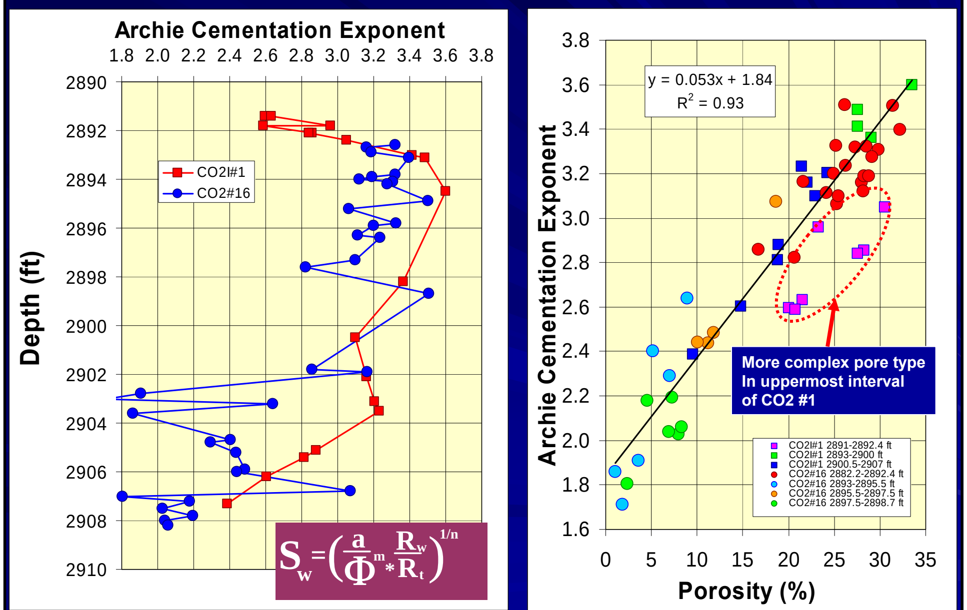
Permeability and Pore Diameter



Pleistocene cores (*light blue*) exhibit correlation of permeability and principal pore throat diameter consistent with trend of other lithologies.

Byrnes et al. (2006)

Comparison of core analysis from CO2 #1 and #16: Consistent upward increase in Archie Cementation Exponent, m, which is closely related to increasing porosity.

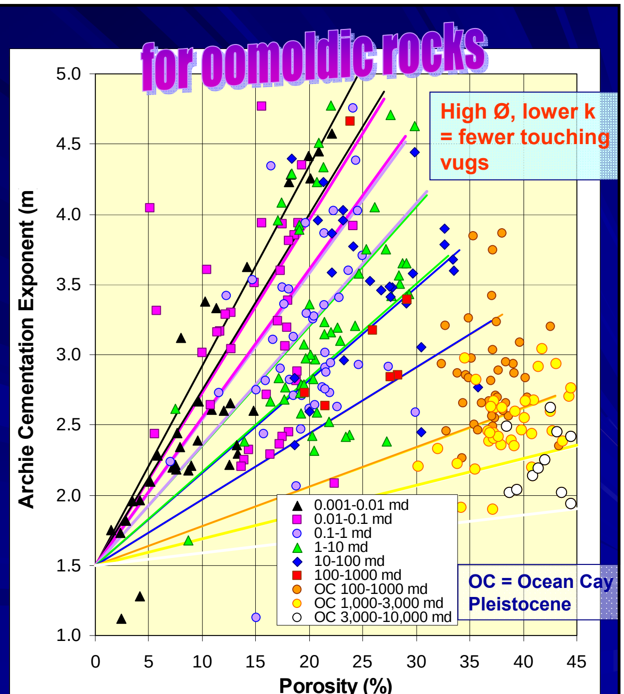


Byrnes et al. (2007)

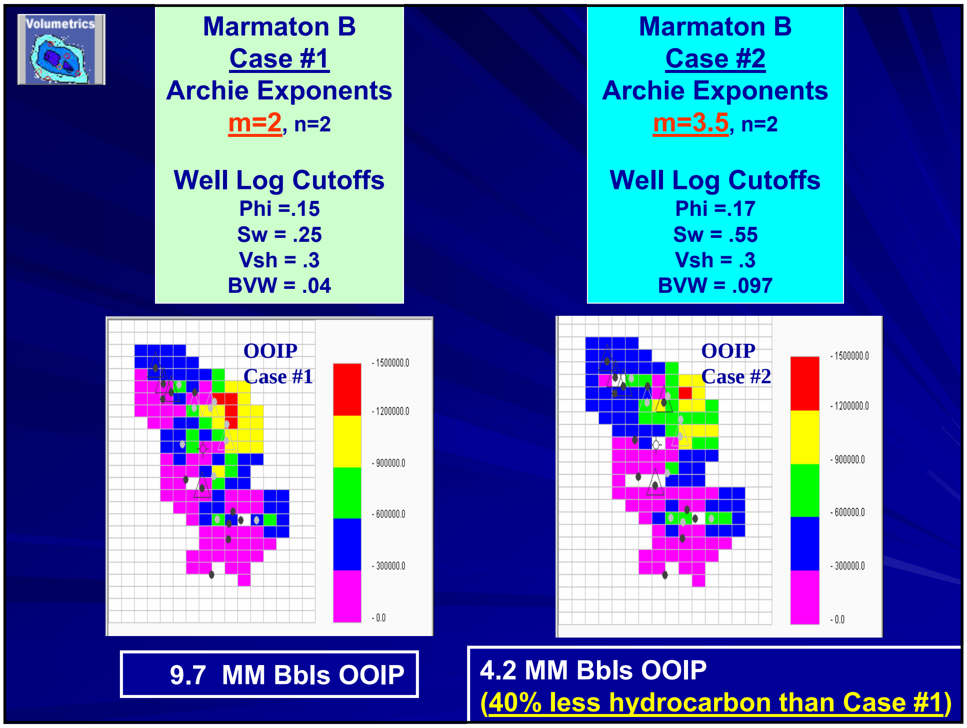
m vs ϕ

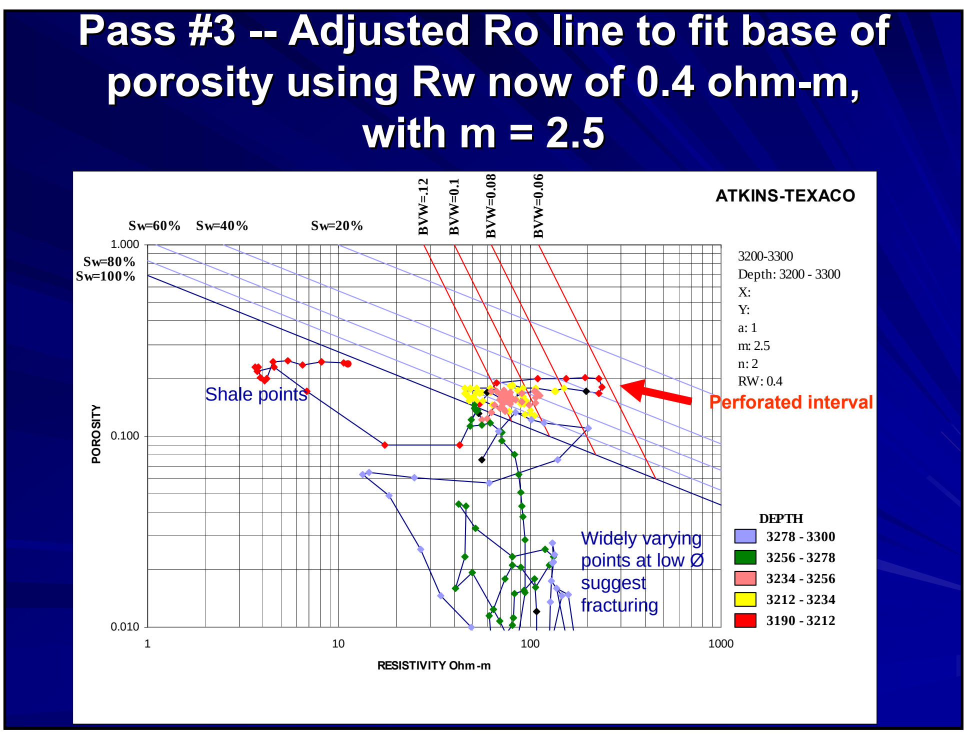
- $m = f(\phi, A_{pore})$
- $m = f(\phi, k)$
- $m = (-0.019 \log_{10} k + 0.085)\phi + 1.5$

Model for estimating m in oomoldic petrofacies knowing k and phi

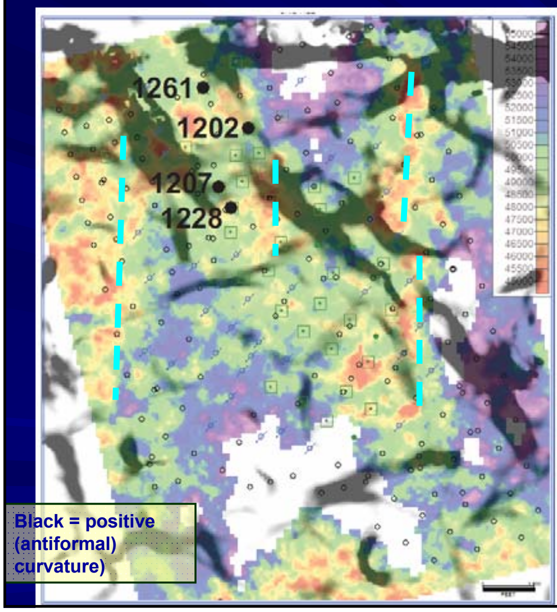


Byrnes et al. (2007)


Volumetrics
Marmaton B
Case #1
Archie Exponents
m=2, n=2
Well Log Cutoffs
Phi =.15
Sw = .25
Vsh = .3
BVW = .04
Marmaton B
Case #2
Archie Exponents
m=3.5, n=2
Well Log Cutoffs
Phi =.17
Sw = .55
Vsh = .3
BVW = .097
OOIP
Case #1
OOIP
Case #2
9.7 MM Bbls OOIP
4.2 MM Bbls OOIP
(40% less hydrocarbon than Case #1)


Pass #3 -- Adjusted Ro line to fit base of porosity using Rw now of 0.4 ohm-m, with m = 2.5
ATKINS-TEXACO
Sw=60%
Sw=40%
Sw=20%
Sw=80%
Sw=100%
BVW=.12
BVW=0.1
BVW=0.08
BVW=0.06
3200-3300
Depth: 3200 - 3300
X:
Y:
a: 1
m: 2.5
n: 2
RW: 0.4
Shale points
Perforated interval
Widely varying points at low Ø suggest fracturing
POROSITY
RESISTIVITY Ohm-m
DEPTH
3278 - 3300
3256 - 3278
3234 - 3256
3212 - 3234
3190 - 3212

Most positive volumetric curvature extracted along a *Devonian horizon* superimposed on mean impedance map for base of karst to "X" marker



- Significant deep-seated structural control to the northwest-trending features in the "high volume area".
- Crosscutting north to northeast-trending features on the Devonian surface appear to have impacted porosity development in the San Andres.